SS433: outflows here and there

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Abstract. We summarize the results of VLBA and global VLBI observations of SS433 between 1995 and 2000. With these observations we resolve the inner jet of the source and identify an absorption region ($\sim$ 25 AU), the "central radio gap". The radio gap is caused by free-free absorption of the jet radio emission by a flattened outflow from the binary system. Radio emission is detected on 100 AU scales perpendicular to the normal jets ("equatorial emission region"; "equatorial outflow"). At some epochs the emission is smooth but compact features are frequently detected. We suggest that equatorial outflows may be common in microquasars.

1. The radio inner jets

The radio inner jets resemble those in AGN in that the jet length is roughly inversely proportional to the frequency, and a "core-shift" is observed between 1.6 and 5 GHz — indicative of self-absorption [1]. The differences are that the SS433 jet is ballistic, it contains protons, and a large fraction of the jet material is probably thermal.

The approaching and receding jet sides are separated by a radio gap, as was predicted by Stirling, Spencer & Watson [2]. This is caused by free-free absorption due to a disk-like outflow from the central binary system. The brightness ratio of the two jet sides increases with frequency, and at 22 GHz the receding jet is almost completely absorbed (Fig. 1). The frequency dependence of the size of the mas-scale jet is demonstrated in Fig. 2. The Gaussian FWHM of the main jet feature on the approaching jet side is proportional to $\nu^{-0.93}$ at an epoch when the inner jets were detected up to 22 GHz. The apparent brightness temperature does not show a strong frequency dependence; it is $\sim 10^9$ K on the approaching, and $\sim 10^8$ K on the receding jet side. At 1.6 GHz the brightness ratio reflects only the Doppler-boosting effect and there seems to be no significant free-free absorption on scales larger than $\sim$50 AU (assuming a distance of 5 kpc).

During large flares the inner jet region might disappear, and pairs of plasmons are ejected from the system. There is indication for ongoing electron acceleration in these jet components (Paragi, Stirling & Fejes, these proceedings).

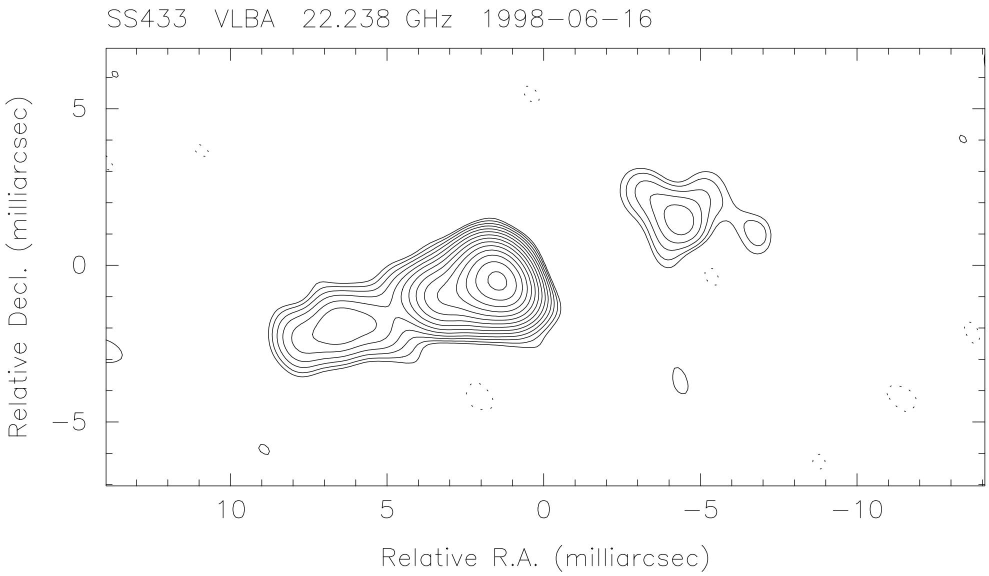

Figure 1. VLBA image of SS433 at 22 GHz on 16 June 1998 (natural weighting). Contour levels increase by a factor of square root 2, the lowest contour is ±1% of the peak brightness (60.1 mJy/beam). The beam FWHM is 1.61×1.15 mas, its major axis is oriented at 33.3 degrees.

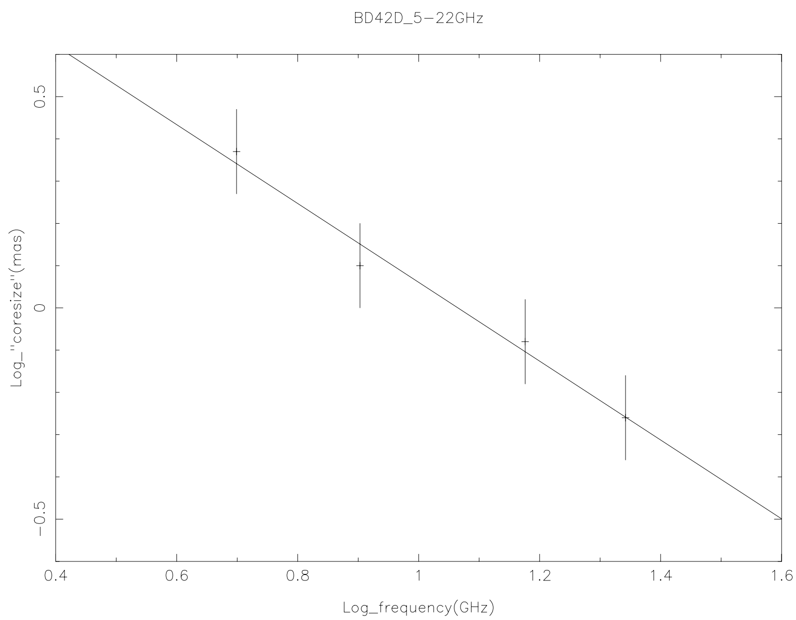

Figure 2. Frequency dependence of the deconvolved Gaussian FWHM size of the main jet component on the approaching jet side on 16 June 1998, when SS433 was detected up to 22 GHz. The fitted "core size" is proportional to $\nu^{-0.93\pm0.20}$. The brightness temperature remains roughly constant, it is order of 10^9 K.

2. The equatorial outflow

We identified a radio emitting region perpendicular to the normal jets [1] which was confirmed in a 1998 experiment (Fig. 3). As there were indications from ob-

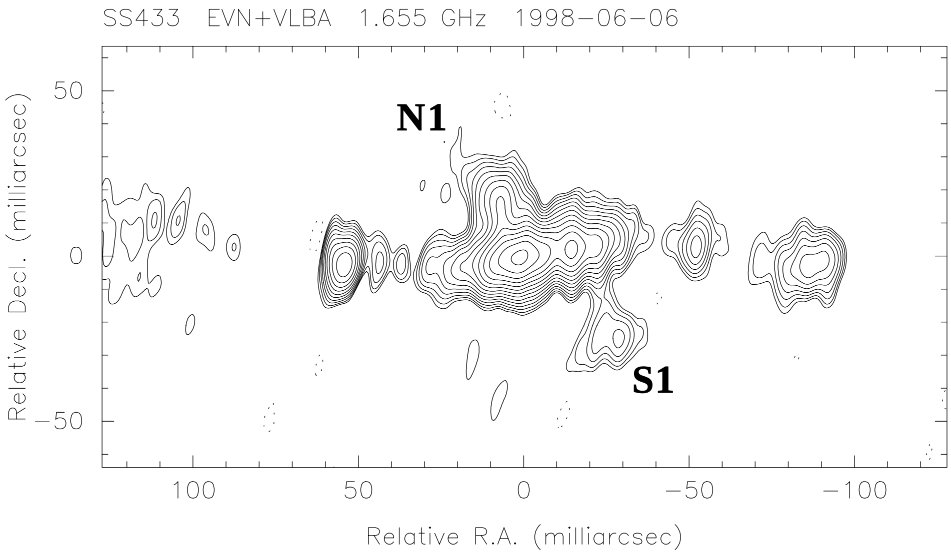

Figure 3. Global VLBI image of SS433 at 1.6 GHz on 6 June 1998 (natural weighting). The Northern equatorial component (N1) was also detected at 5 GHz at two epochs (Paragi, Fejes & Szabó, these proceedeings). Its brightness temperature at 1.6 GHz is 2×10^8 K. Contour levels increase by a factor of square root 2, the lowest contour is $\pm 1\%$ of the peak brightness (38.3 mJy/beam). The beam FWHM is 10.7×3.76 mas, its major axis is oriented at -5.8 degrees.

servations, numerical simulations [3] and theoretical works [4] that a significant fraction of the accreted matter leaves the system in its equatorial plane, we refer to this region as the Equatorial Outflow. We stress that the outflow is not constrained in a narrow plane, the term "equatorial" refering to the fact that the region is not related to the radio beams of SS433 that emanate from the poles of the central engine. An independent group also observed this outflow (Blundell et al., these proceedings).

Emission from the equatorial outflow has been detected in seven VLBI experiments. The region is sometimes smooth, but compact, brighter features appear frequently. One of these components was observed to move away from the centre at a projected speed of 1200 ± 500 km/s (Paragi, Fejes & Szabó, these proceedings). This is significantly larger than the estimated terminal wind speed of $\sim$300 km/s [5, 6]. Fabrika suggested that the faster disk wind ($\sim$1500 km/s) could develop shock waves into the slow ($\sim$100 km/s) outflow from time to time, as the disk precesses. Another possibility is that the components are shocks resulting in a jet-ISM interaction. In Fig. 4 we see the emergence of a new equatorial feature from the central region, close to the approaching Eastern jet.

Based on IR measurements Fuchs et al. (these proceedings) estimated a mass-loss rate of $\sim 10^{-4}$ $M_{\odot}$/yr assuming spherical symmetry. This result indicates that most of the accreted matter leaves the system in this flow rather than the radio jets. There are at least two other HMXBs where observations indicate a large-scale outflow embedding the binary system [7, 8]. For this reason we suggest that equatorial outflows may be common in HMXB microquasars.

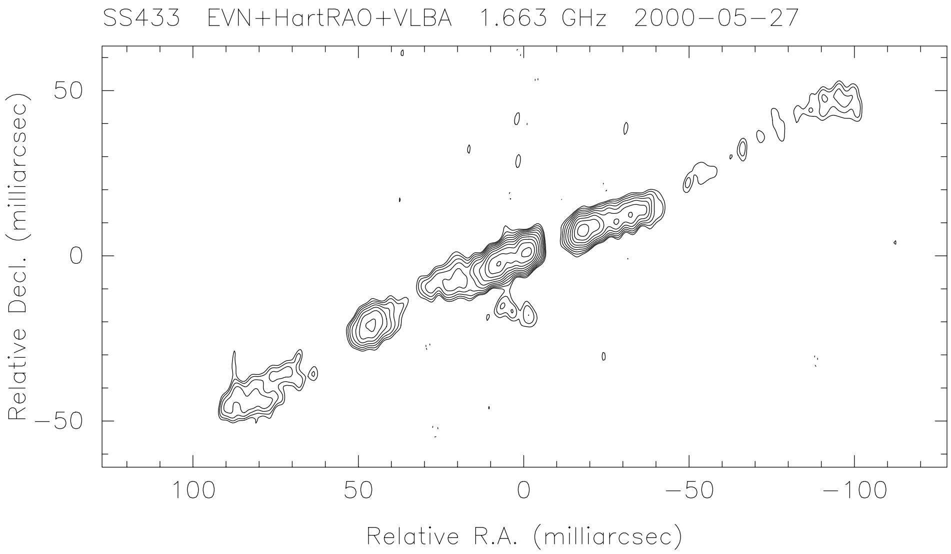

Figure 4. Global VLBI image of SS433 at 1.6 GHz on 27 May 2000. We used uniform weighting for this image, which results in the highest possible resolution (and an increasement in the image noise at the same time). The inclusion of Hartebeesthoek in the array improved the N–S resolution significantly. The equatorial component is separate from the jet, but appears very close to it. Contour levels increase by a factor of square root 2, the lowest contour is ±4% of the peak brightness (14.9 mJy/beam). The beam FWHM is 4.85×2.82 mas, its major axis is oriented at −8.4 degrees.

Acknowledgments

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Proper motion detected in the equatorial outflow of SS433 (poster)

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Abstract. The equatorial outflow in SS433 has been observed in seven VLBI experiments using the VLBA and the EVN. Emission is generally detected at only 1.6 GHz, but there are two epochs when bright features are observed also at 5 GHz. One of these radio components is detected at three epochs, and appears to move outward from the central region at a projected velocity of $\sim 1200 \pm 500$ km/s.

1. Introduction

Since the Very Long Baseline Array observed SS433 in a multi-frequency experiment in 1995, it has been known that microquasars may produce radio emission not only in the well-studied jets, but also in their equatorial region [1, 2]. Because the presence of an outflow had been suggested based on observations in the optical and in X-ray [3, 4], the radio emission was naturally attributed to this equatorial flow. Recent works in the UV [5] and IR regimes (Fuchs et al., these proceedings) also support this scenario. We initiated VLBA and global VLBI (EVN+Hartebeesthoek+VLBA) observations to monitor changes in this region on milliarcsecond scales.

2. Detected proper motion

The existence of the equatorial emission region was confirmed by 1.6 GHz global VLBI observations (see Fig. 3 of Paragi et al., these proceedings) on 6 June 1998. There were two radio components (indicated by N1 and S1), as in 1995, but their separation and position angle were different. N1 had a brightness temperature of 2×10^8 K, indicative of a non-thermal emission mechanism. It was also identified at 5 GHz on 22 May and 16 June 1998 (see Fig. 1).

Because the jets precess and there is no well-determined, compact feature in the centre on milliarcsecond (mas) scales, it is difficult to find a good reference point in the source. We assumed that the binary is located in the middle of the radio gap [2]. The separation of N1 from this reference point increased significantly. By assigning a 1 mas error to the position measurements (including the uncertainty in the reference point), we determined an outward proper motion of $\mu = 0.14 \pm 0.06$ mas/day. If this is due to a bulk motion of matter, this corresponds to an outflow velocity of $(1200 \pm 500)/\sin(i)$ km/s.

Changes in the region were further monitored in 2000 with a global VLBI network (images not shown here). The results from these experiments can be found in [6].

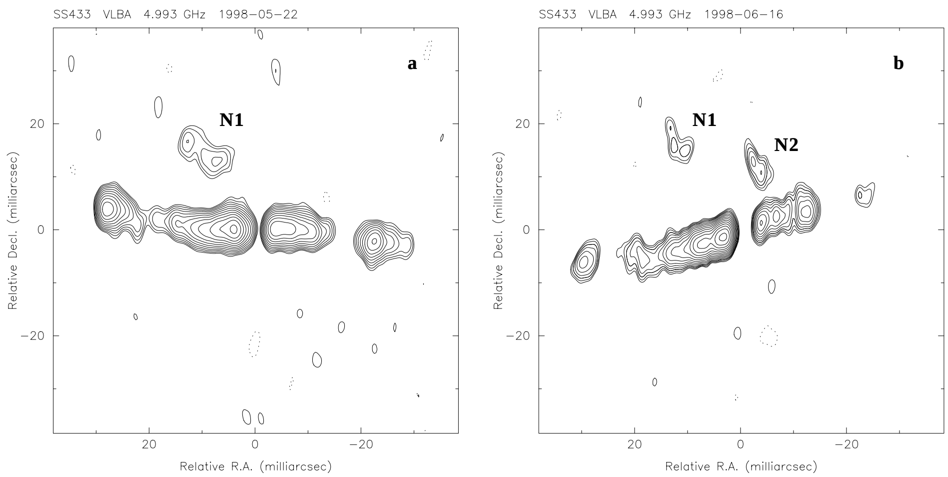

Figure 1. Component N1 as observed on 22 May 1998 (**a**) and 16 June 1998 (**b**) at 5 GHz. Contour levels increase by a factor of square root 2, the lowest contoures are ±2% and ±1%. The peak brightness, beam FWHM size and orientation is as follows: **a)** 23.6 mJy/beam, 4.06×1.86 mas, 0.6 degrees; **b)** 47.3 mJy/beam, 3.57×1.51 mas, 0.1 degrees.

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Electron acceleration in SS433 jet components (poster)

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Abstract. We present multi-frequency VLBA observations of SS433 during an outburst. Our data suggests that electron acceleration is taking place in the radio plasmons ejected from the central source.

1. Structural changes and spectral properties

We observed SS433 with the VLBA (5, 8.4, 15 and 22 GHz) on 18 April 1998 during a large flare. The core-jet region of the source disappeared in the flare. Instead we detected four pairs of plasmons ejected from the centre (Fig. 1). Most of these components (except E1) had a very steep spectrum between 5 and 8.4 GHz. Interestingly, the spectrum between 15 and 22 GHz was somewhat flatter. The spectral properties of the plasmons are shown in Fig. 2, on the colour–colour ($\alpha_{15-22} - \alpha_{5-8.4}$) diagram [1].

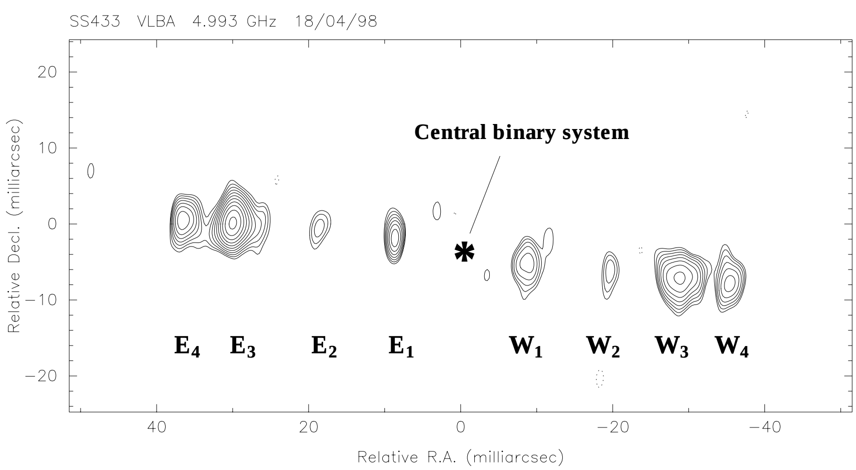

Figure 1. Radio plasmons of SS433 observed with the VLBA on 18 April 1998 at 5 GHz. The brightest component (E3) had a brightness temperature of 2×10^9 K. Contour levels increase by a factor of square root 2, the lowest contour is ±2.82% of the peak brightness (109.7 mJy/beam). The beam FWHM is 3.71×1.55 mas, its major axis is oriented at −2.5 degrees.

The components are already in the optically thin phase of their evolution at the observing frequencies. At this epoch the flare had not yet reached its maximum. The most straightforward explanation for an increasing flux density during the optically thin phase is that a new generation of electrons was accelerated in the plasmons. A similar conclusion was reached using single dish radio flux density measurements by Seaquist et al. [2].

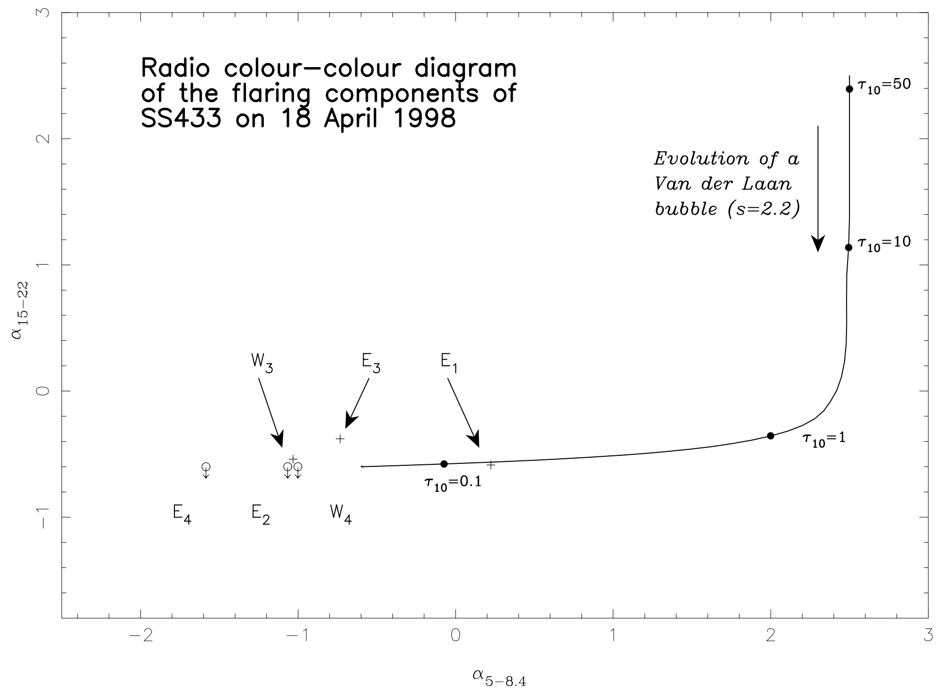

Figure 2. The radio colour–colour diagram of SS433 jet components. The spectral evolution of a “Van der Laan bubble” and its optical depth at the reference frequency of 10 GHz is also shown. For some components there are only upper limits available for the high-frequency spectral index. W2 was too faint even at 8 GHz; W1 lies outside the ranges shown. The electron energy spectral index used in the model is s=2.2.

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